



MEASUREMENT OF THE ISOLATED PHOTON PRODUCTION CROSS SECTION IN PP COLLISIONS AT 7 TEV

PRL 106 (2011) 082001

April 14, 2011

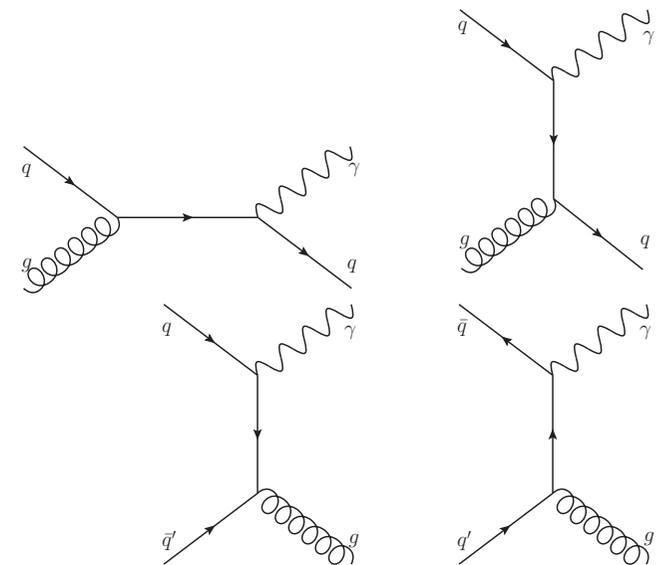
DIS 2011

Prompt photons

- A test of perturbative QCD.
- A probe of (gluon) parton distribution functions.
- A background to searches. (e.g. $\text{Higgs} \rightarrow \gamma \gamma$)

- Production mechanisms:

- **Quark-gluon Compton scattering.** →
 - Dominant at the LHC.
 - Quark-antiquark annihilation. →
 - Fragmentation of colored partons.





Isolated photons

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- Studied experimentally since 30 years:
 - ▣ Large contamination from the decay of energetic neutral mesons.
 - ▣ Experimentally accessible objects: **isolated photons**.
 - ▣ Main handles:
 - track and calorimeter sums,
 - shower shapes.

- Theoretical calculations can provide isolated part of the cross section.
 - ▣ Implemented as a phase-space integration of fragmentation functions.



Recent results on isolated photons

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PLB 639, 151 (2006) & 658, 285(E) (2008)

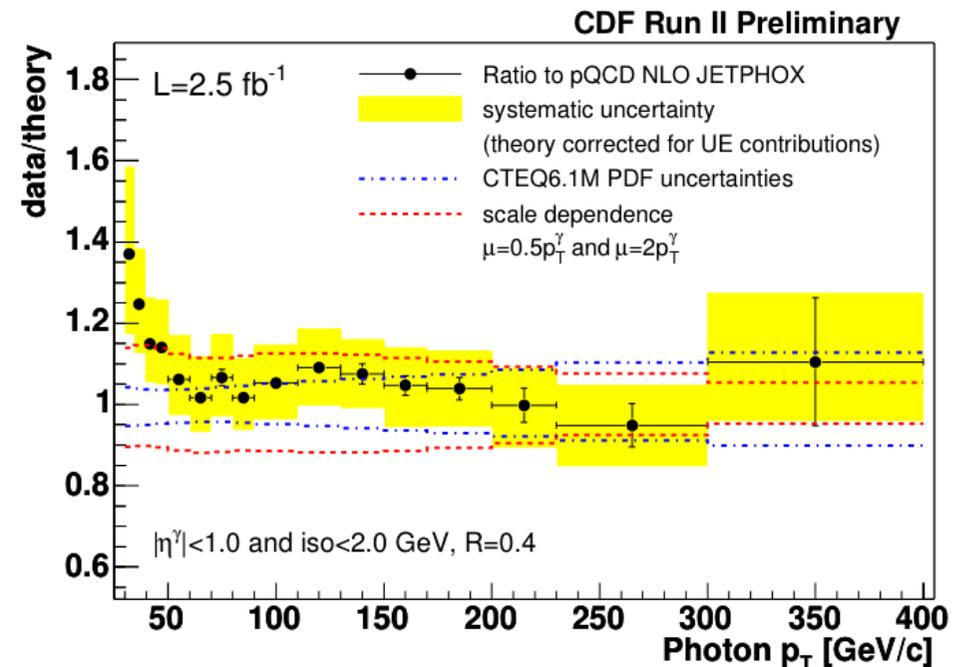
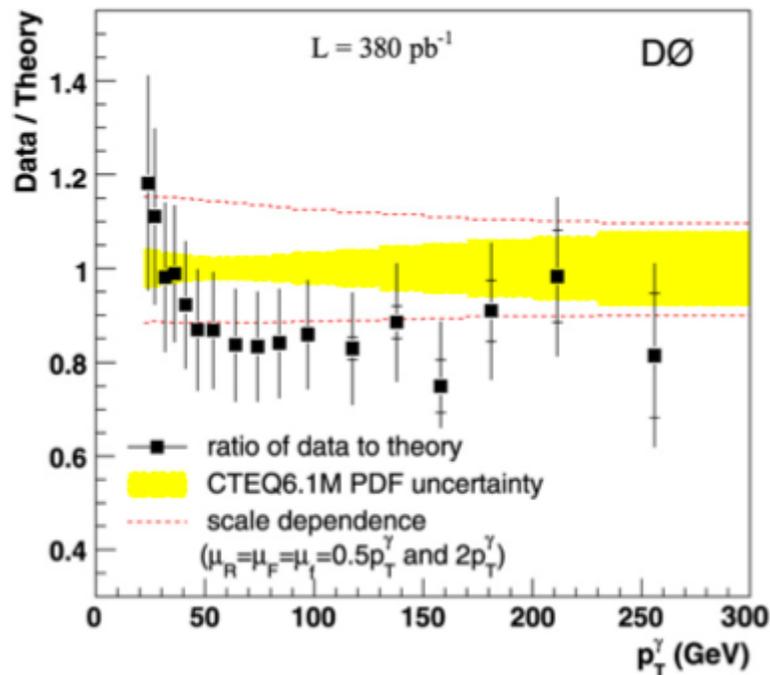
PRD 80, 111106 (2009)

□ DØ 2006/2008

- ppbar at 1.96 TeV.
- **Syst. Uncertainty 10 – 20%**

□ CDF 2009

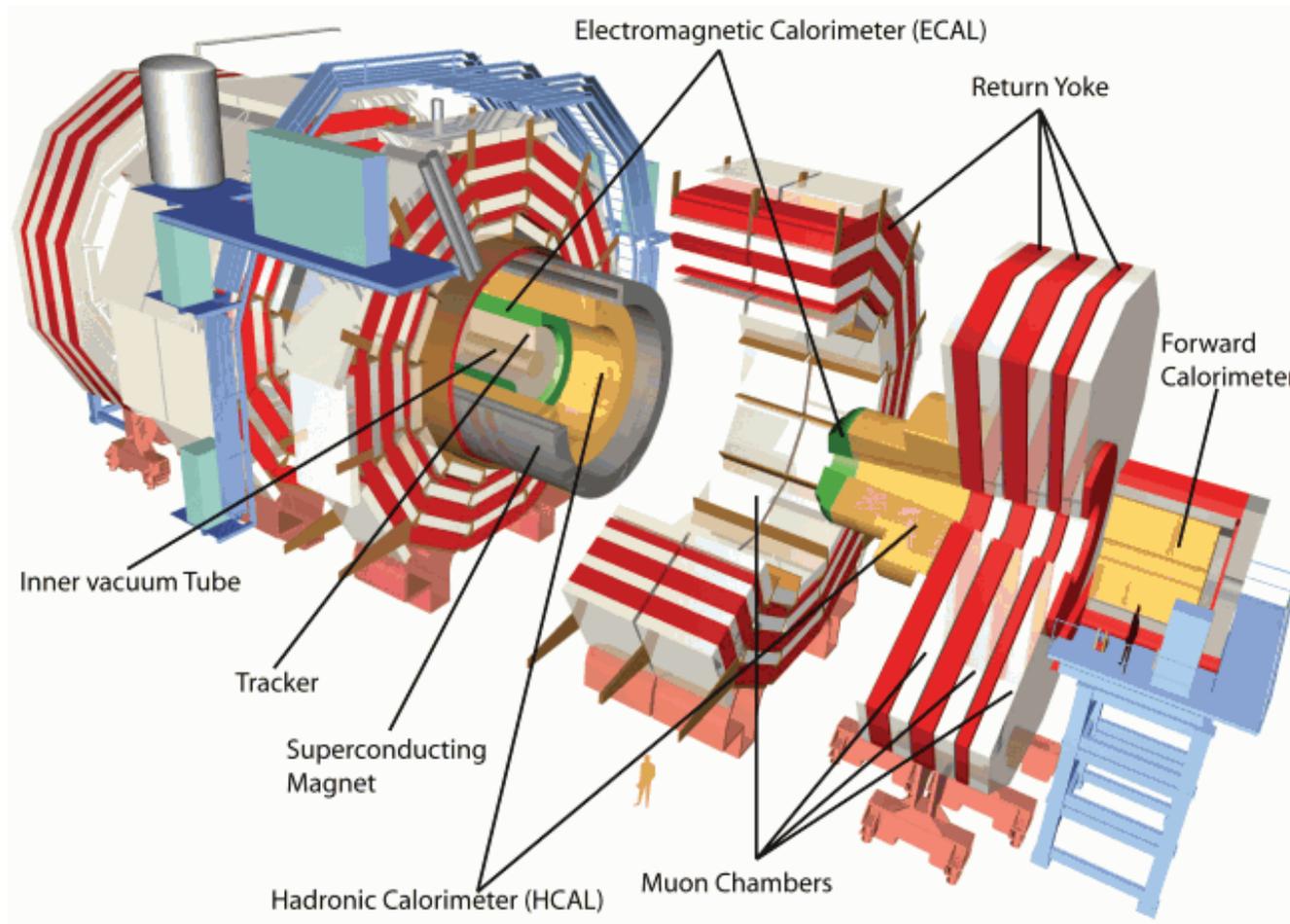
- ppbar at 1.96 TeV.
- **Syst. Uncertainty 10 – 15%**





The CMS detector

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Overview of the measurement

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$$\frac{d^2\sigma_{\text{Isolated}}}{dE_T^\gamma d\eta^\gamma} = \frac{1}{\Delta E_T^\gamma \Delta \eta^\gamma} \frac{N^\gamma(\Delta E_T^\gamma, \Delta \eta^\gamma)}{L \cdot U(\Delta E_T^\gamma) \cdot \varepsilon}$$

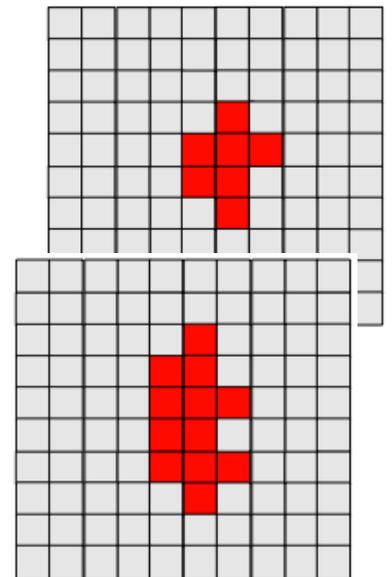
- Isolated photon cross section.
 - ▣ **generator-level hadronic E_T below 5 GeV within $R=0.4$.**
- Phase-space probed:
 - ▣ $|\eta^\gamma| < 1.45$ (CMS ECAL barrel).
 - ▣ E_T^γ bins: 21–300 GeV (11 bins).
- N^γ – the estimated number of isolated photons
- L – luminosity
- U – correction for reconstruction effects
- ε – efficiency and acceptance



Handles for photon signal yield extraction

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- Main background for isolated photons are neutral mesons decaying into 2γ .
- Two main tools to disentangle:
 - Candidate isolation in Tracker, ECAL, HCAL.
 - Shower shape in ECAL. ↘





Strategy for photon signal yield extraction

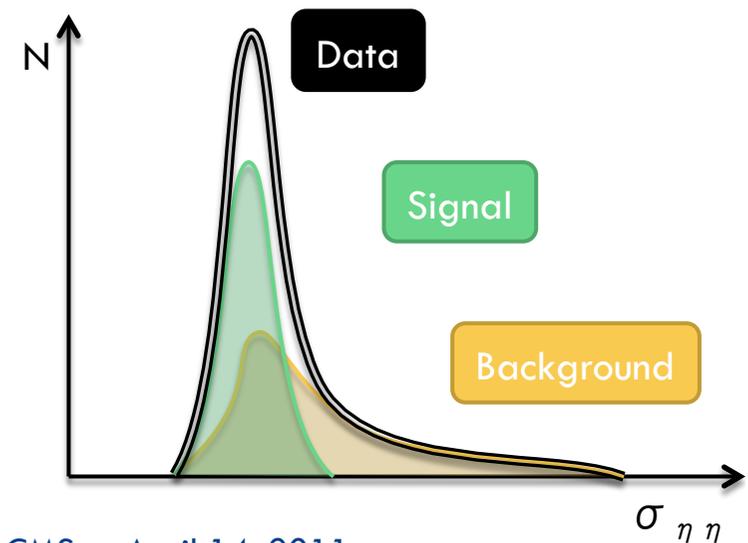
8

- **Perform photon ID with isolation requirements** to enrich sample in prompt photons.
- **Use $\sigma_{\eta\eta}$ shower shape variable** to extract signal and background yields from data.

$$\sigma_{\eta\eta}^2 = \frac{\sum (\eta_i - \bar{\eta})^2 w_i}{\sum w_i}, \quad \bar{\eta} = \frac{\sum \eta_i w_i}{\sum w_i}$$

$$w_i = \max(0, 4.7 + \log(E_i / E_{5 \times 5}))$$

NIMA 311, 130 (1992)



Photon candidate ID

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□ Robust start-up selection →

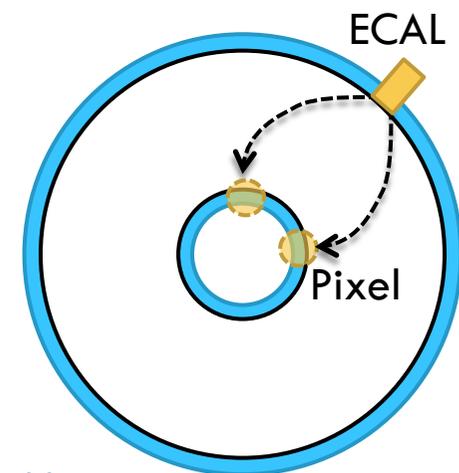
□ Small set of variables

- $Iso_{TRK} = \sum_{R<0.4} \text{track } p_T$
- $Iso_{ECAL} = \sum_{R<0.4} E_{T \text{ ECAL}}$
- $Iso_{HCAL} = \sum_{R<0.4} E_{T \text{ HCAL}}$
- $H/E = \sum_{R<0.15} E_{HCAL}/E_{ECAL}$
- Pixel seed veto →

□ Criteria away from simulation details

| Variable | Selection |
|---------------------------------|---------------------------------|
| Track Isolation (Iso_{TRK}) | $< 2.0 \text{ GeV} + 0.001 E_T$ |
| ECAL Isolation (Iso_{ECAL}) | $< 4.2 \text{ GeV} + 0.003 E_T$ |
| HCAL Isolation (Iso_{HCAL}) | $< 2.2 \text{ GeV} + 0.001 E_T$ |
| H/E | < 0.05 |

(veto events with pixel seeds compatible with electron tracks) ↓



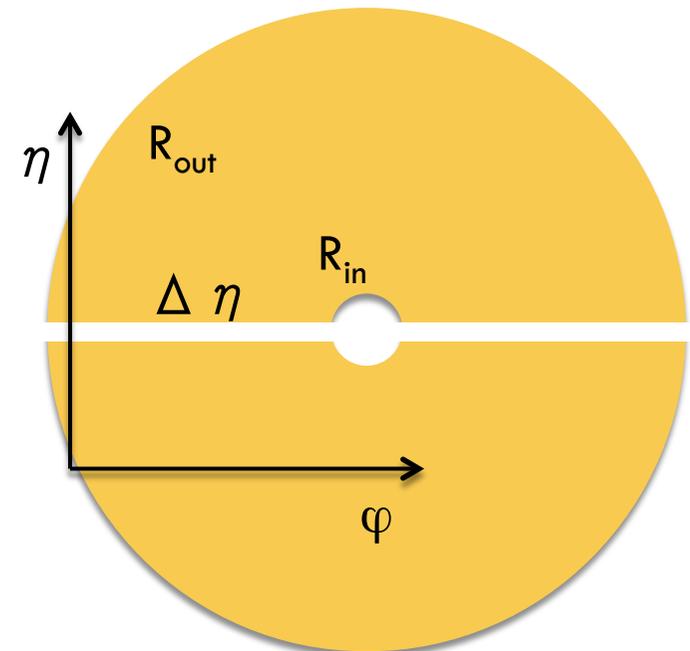


Photon candidate ID: isolation

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- **Hollow cone removing central η strip.**
- Allows the use of (Z) electron control samples:
 - ▣ Fully data-driven corrections.
 - ▣ Insufficient prompt-photon control sample in 2/pb.

| Variable | R_{out} | R_{in} | $\Delta \eta$ |
|--------------|-----------|----------|---------------|
| Iso_{TRK} | 0.4 | 0.040 | 0.015 |
| Iso_{ECAL} | 0.4 | 0.06 | 0.04 |
| Iso_{HCAL} | 0.4 | 0.15 | - |

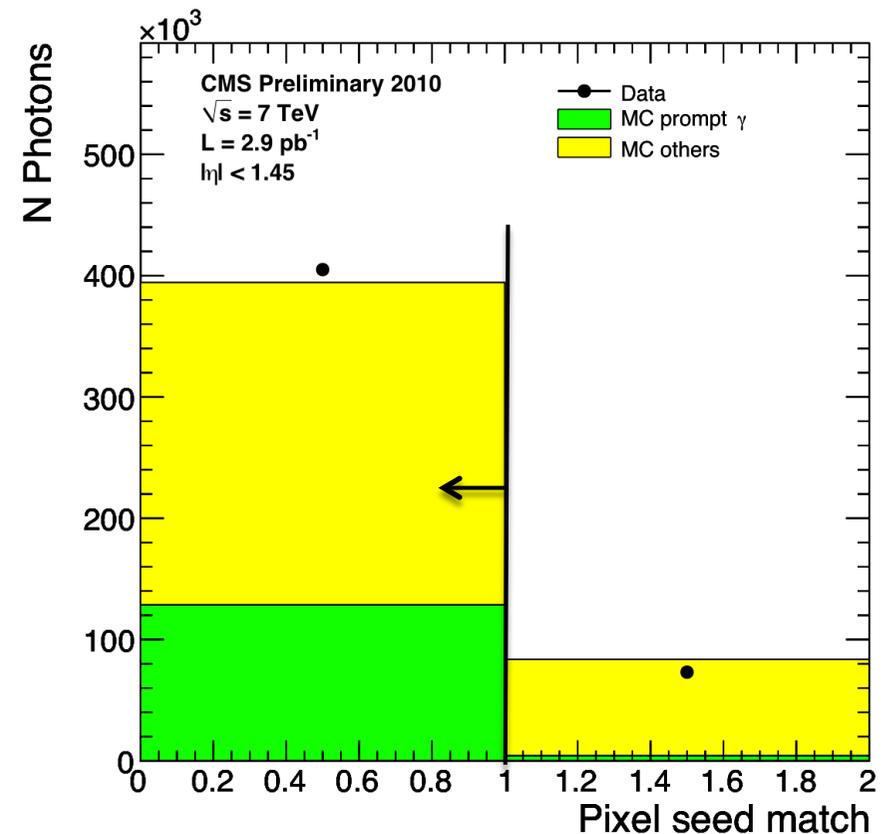
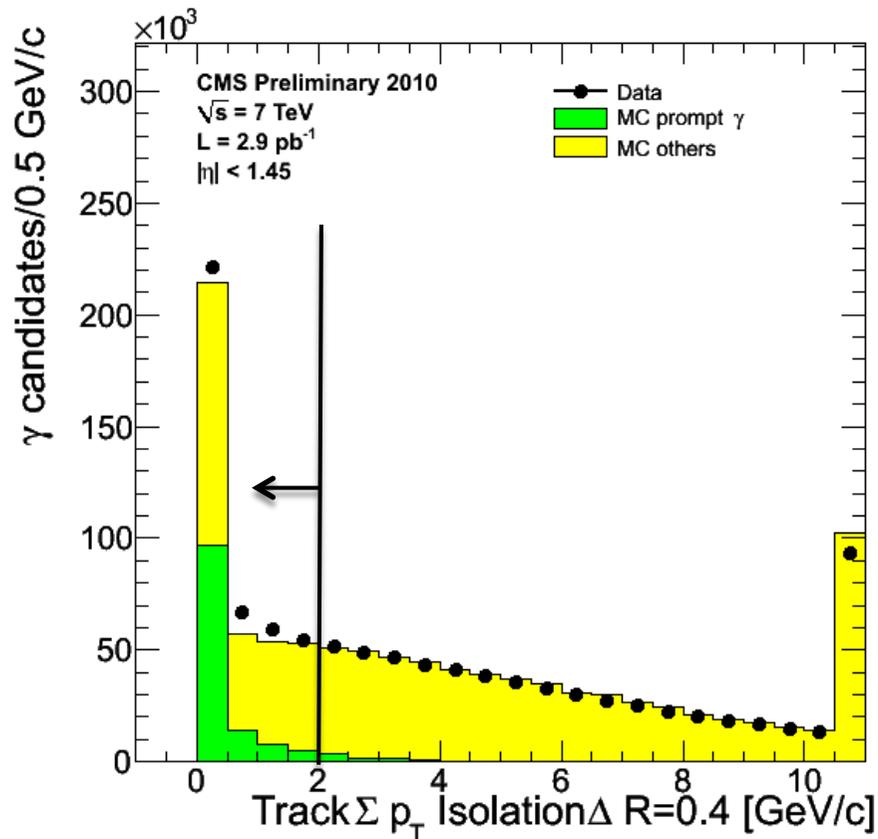




Photon candidate ID: $N-1$ plots

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- All cuts applied except on plotted variable

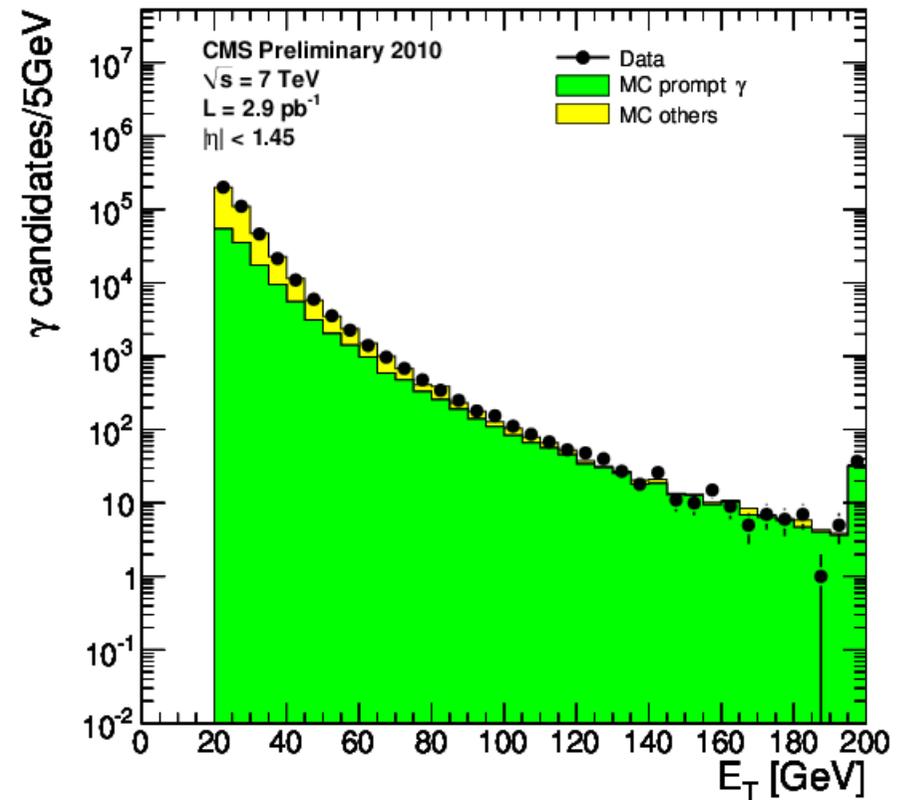
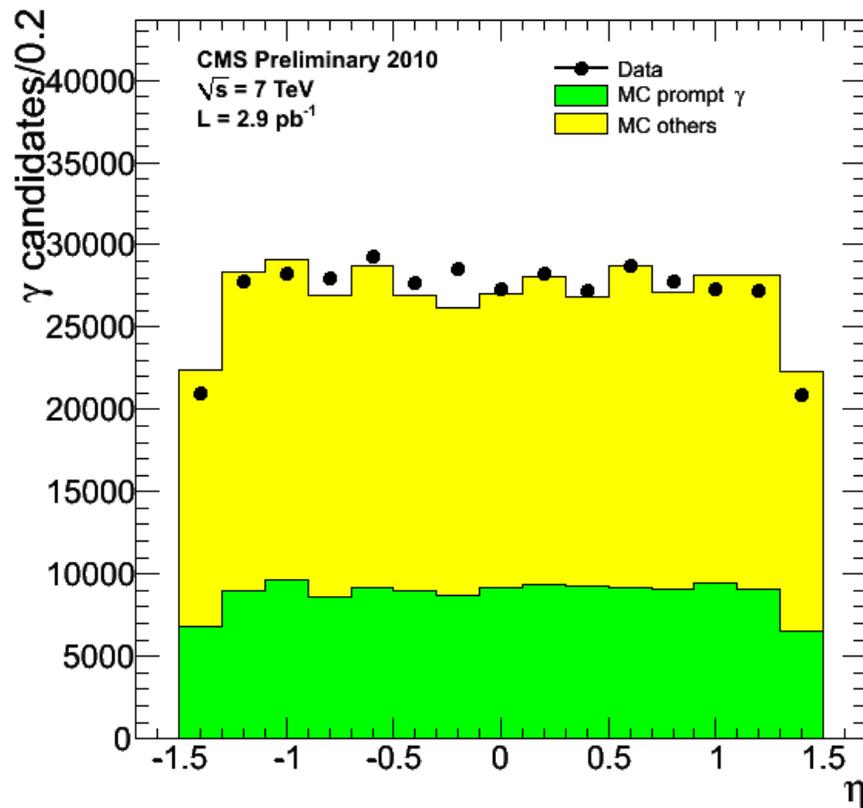




Photon candidates

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- 4×10^5 photon candidates selected
 - ▣ Good description of η^γ and E_T^γ distributions





Overview of the measurement

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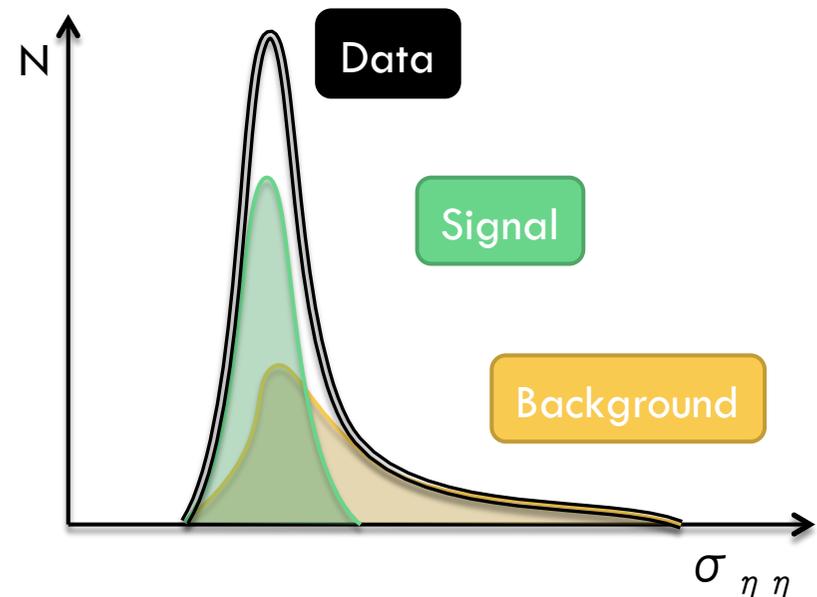
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- Isolated photon cross section
 - ▣ generator-level hadronic E_T below 5 GeV within $R=0.4$
- Phase-space probed
 - ▣ $|\eta^\gamma| < 1.45$ (ECAL barrel)
 - ▣ E_T^γ bins: 21, 23, 26, 30, 35, 40, 45, 50, 60, 80, 120, 300 GeV
- N^γ – the estimated number of isolated photons
- L – 2010A data-set luminosity
- U – correction for reconstruction effects
- ε – efficiency and acceptance



Isolated photon yield extraction

- Two-component fit to the data in each E_T bin: \blacktriangleright
 - **Signal shapes based on MC**
 - Corrections from electron control sample in data.
 - **Background shapes fully data-driven**
 - Using track isolation side-band.



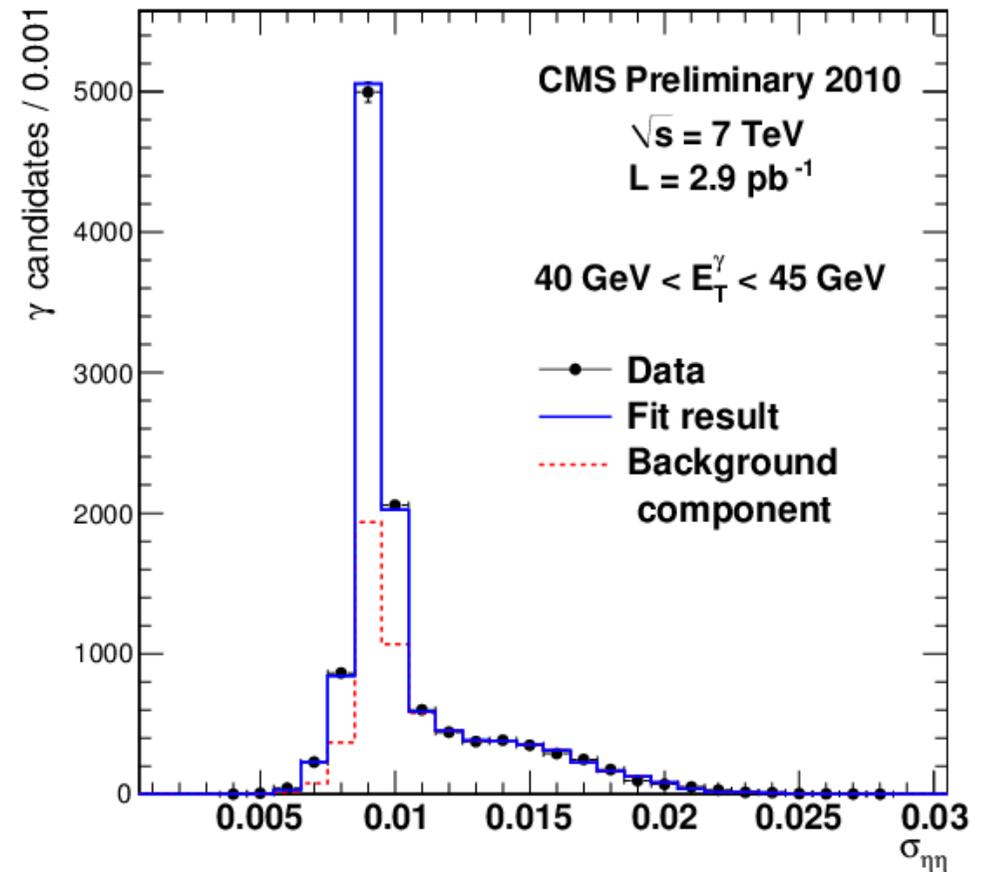
Fit shapes to data using binned maximum likelihood. \blacktriangleright

$$\mathcal{L} = -\ln L = -(N_S + N_B) + \sum_{i=1}^n N_i \ln(N_S \mathcal{S}_i + N_B \mathcal{B}_i)$$



Two-component fit to the data

- Good fit to the data





Overview of the measurement

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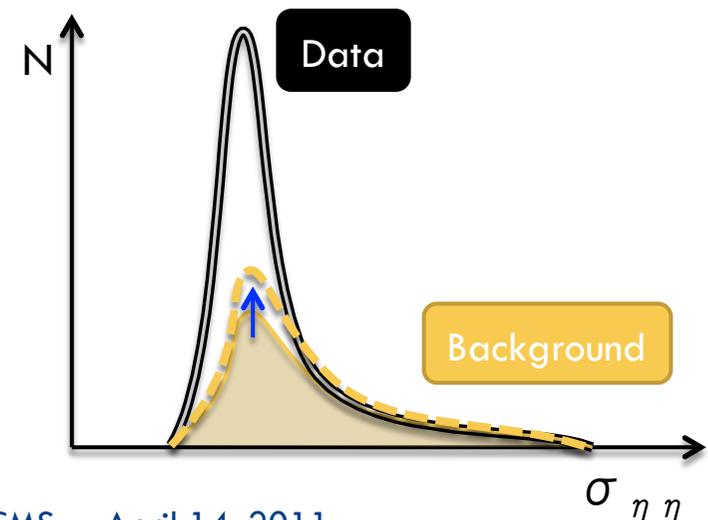
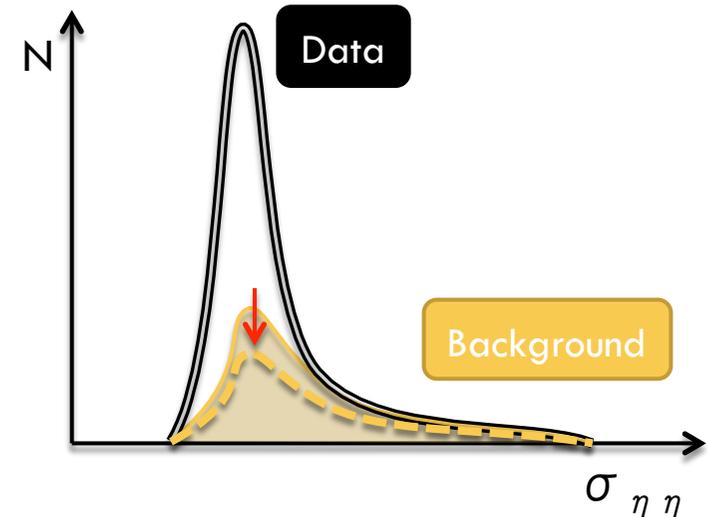
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 - ▣ E_T^γ bins: 21, 23, 26, 30, 35, 40, 45, 50, 60, 80, 120, 300 GeV
- N^γ – the estimated number of isolated photons
- $L = 2.9 \pm 0.3 \text{ pb}^{-1}$ (2010A data-set luminosity)
- $U = 1.01$ to 0.97 with E_T^γ (correction for reco. effects)
- $\varepsilon = 0.916 \pm 0.034$ (efficiency and acceptance)

Background shape systematics

- Two concurrent effects:
 - **Side-band has more Iso_{TRK} activity** than that of background in the signal region
 - Emphasizes tail, depresses peak
 - **Presence of signal** in the non-isolated side-band
 - Emphasizes peak

- Conservative approach: estimated each effect separately.

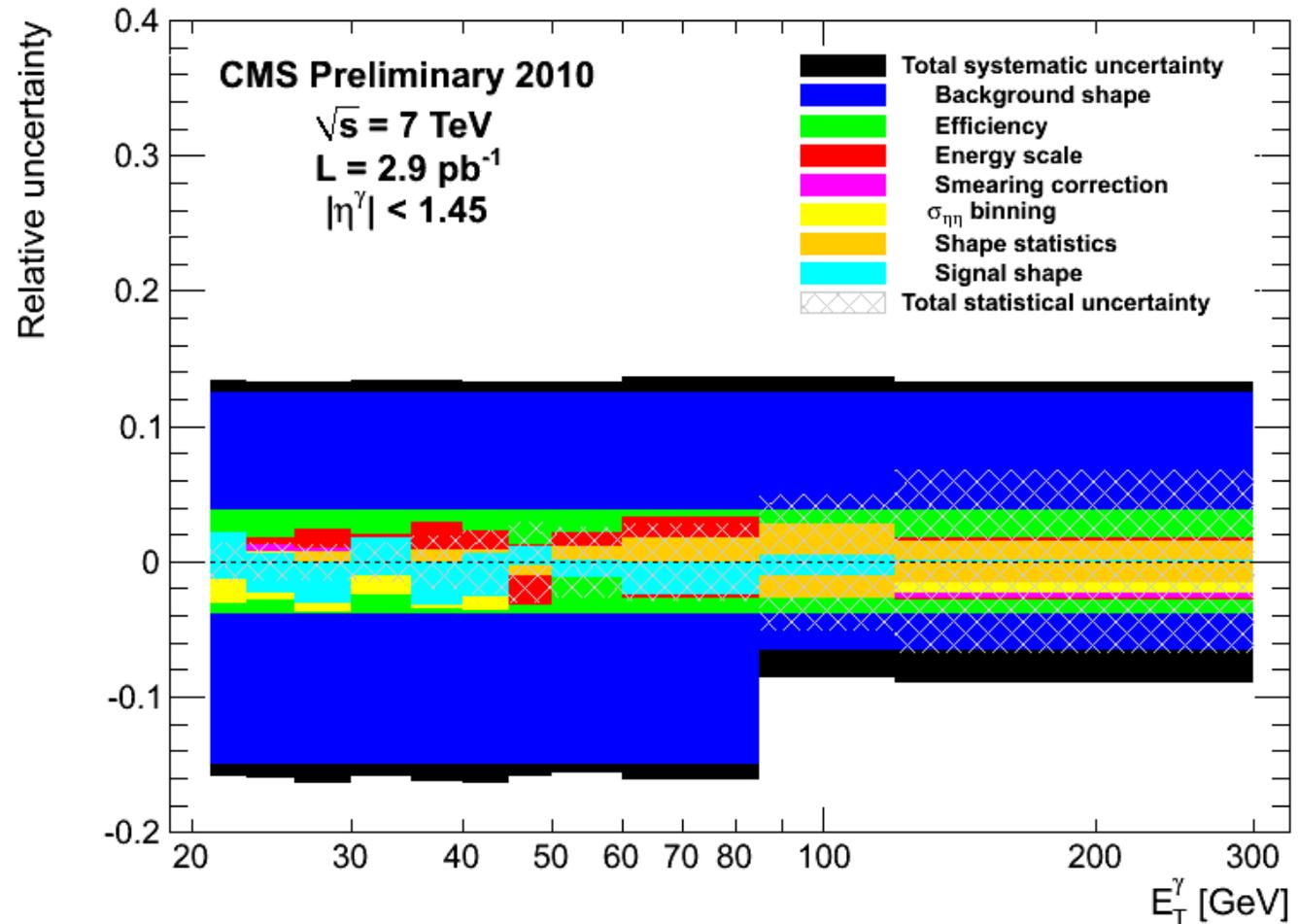




Systematic uncertainty on cross section: breakdown

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- **13–16%**
 - Dominated by background shape
- 11% lumi uncertainty treated separately

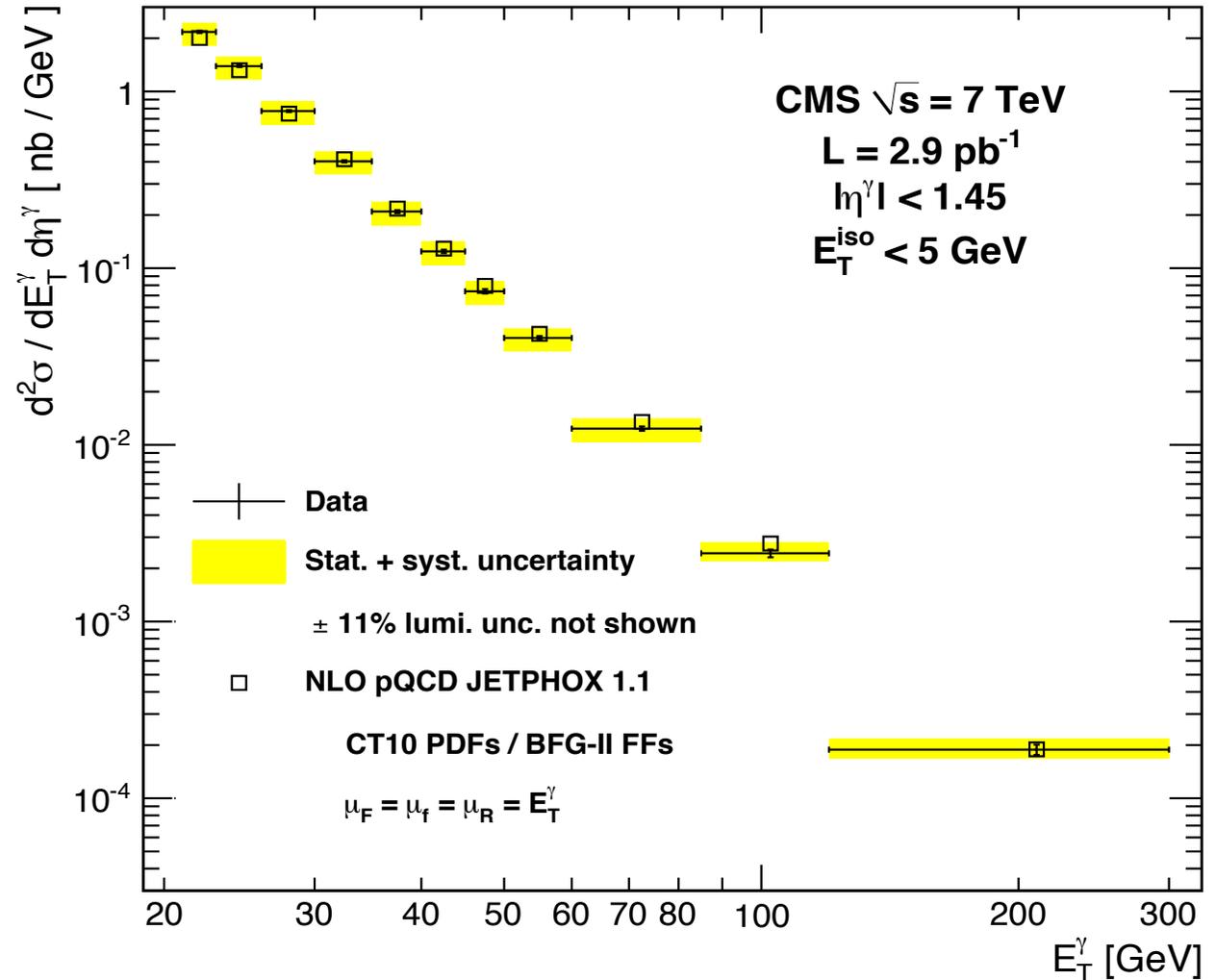




Differential cross section

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- 11% lumi uncertainty not shown

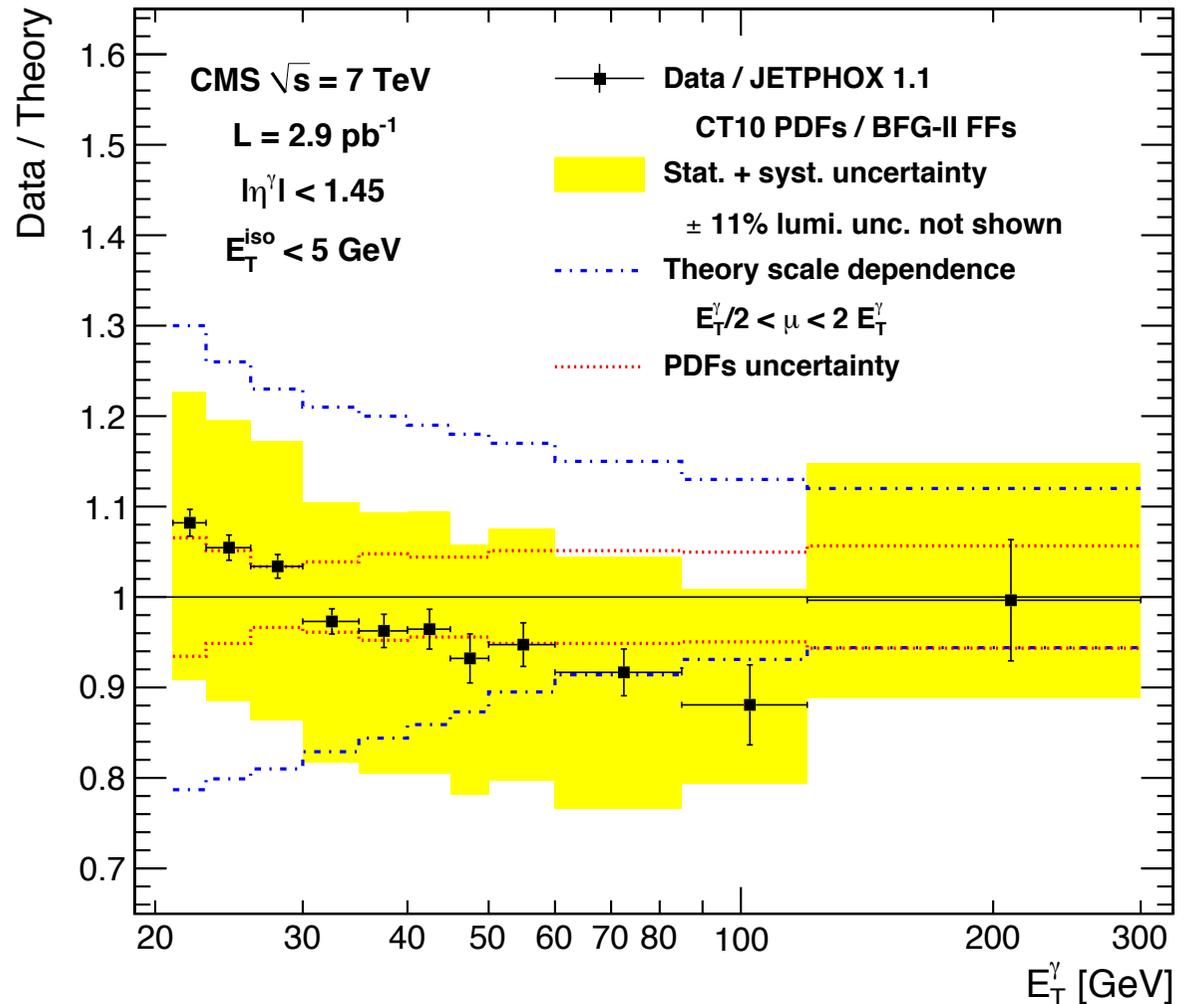




Comparison between theory and data

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- 11% lumi uncertainty not shown





Conclusions

- **First LHC measurement of isolated photons:**
 - Competitive systematics already at start-up.
 - Quite good agreement with theory.
 - PRL 106 (2011) 082001

- Presently busy with:
 - Extension to full ECAL coverage
 - Photons + jets
 - Di-photons

